Motor Research in the Power Electronics and Electric Machinery Group

Jason Pries

OAK RIDGE National Laboratory

CMI Critical Materials Institute
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Outline

- **PEEM Group Overview**
  - **P**ower **E**lectronics
  - **E**lectric **M**achines (Motors)
    - Materials Modeling Research
    - Rare Earth Free/Reduced Electric Machines
- **Recycled Hard Disk Drive Magnet Motors**
- **Additive Manufacturing**
- **Questions and Discussion**

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Accelerating Power Electronics and Electric Motors Technologies

Power Electronics

- Circuit topologies
- Wired and wireless vehicle charging systems
- Wide bandgap devices
- Power quality and utility interconnects
- Advanced Manufacturing

Electric Motors

- Innovative designs
- High-performance non-permanent magnet motors
- Permanent magnet motors
- Advanced materials
- Controls

Packaging

- High efficiency packages
- High temperature packaging
- Highly integrated smart power module

Applied R&D

- Transportation
- Grid
- Renewables

Unique solutions and facilities to meet application needs

Innovative, cost-effective PEEM solutions

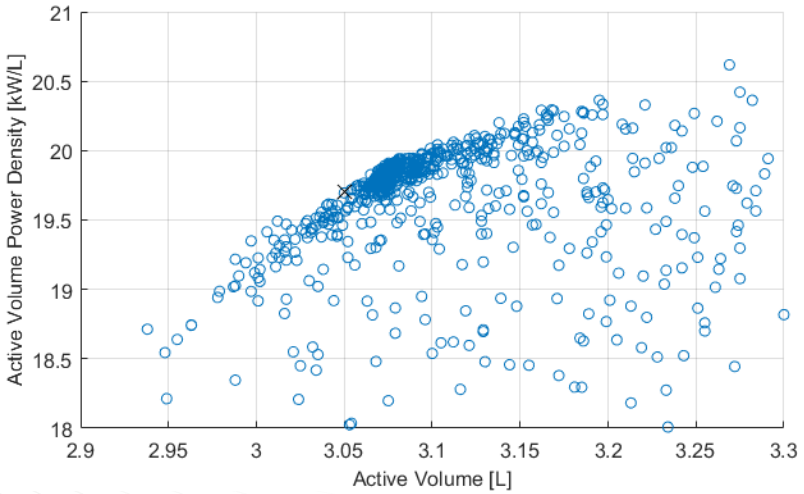
WBG DATA Facility

Power Device Packaging Laboratory

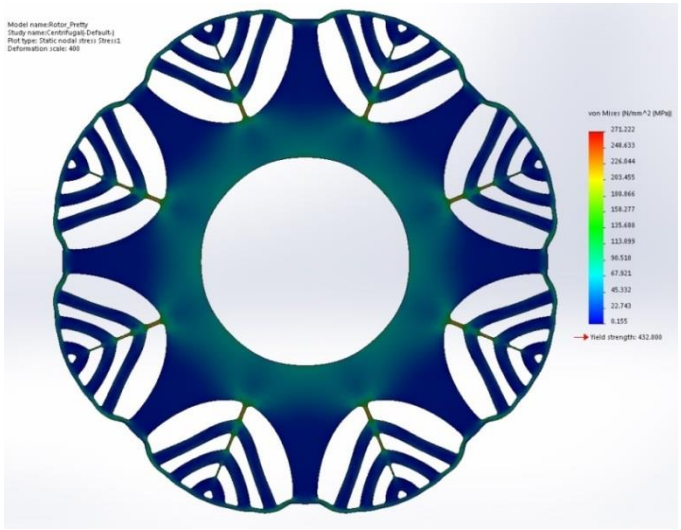
Wireless Vehicle Charging

Novel Flux Coupling Motor

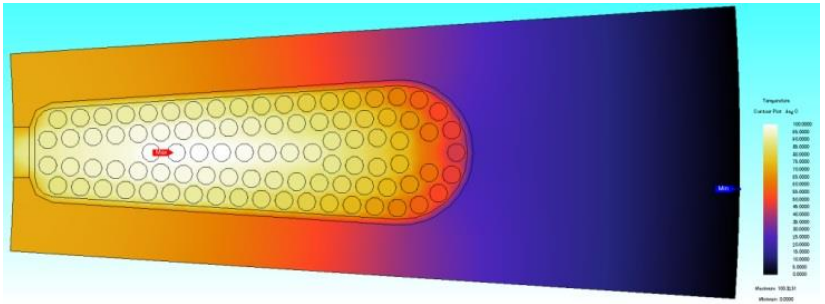
Electric Machine Design and Optimization



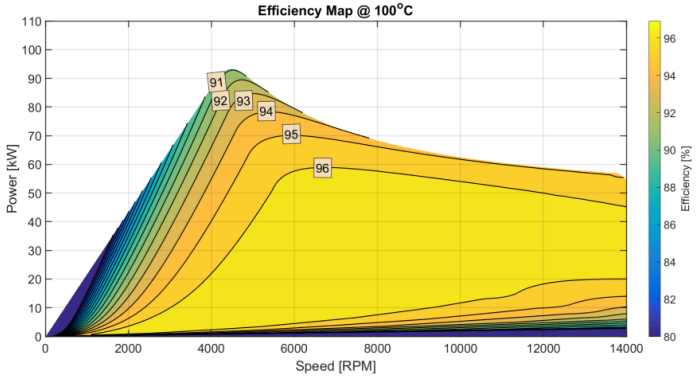
Design optimization using gradient and evolutionary algorithms



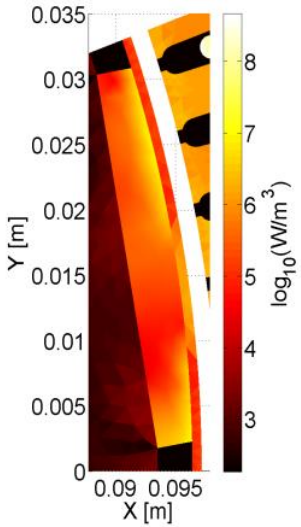
Rotor mechanical stress analysis

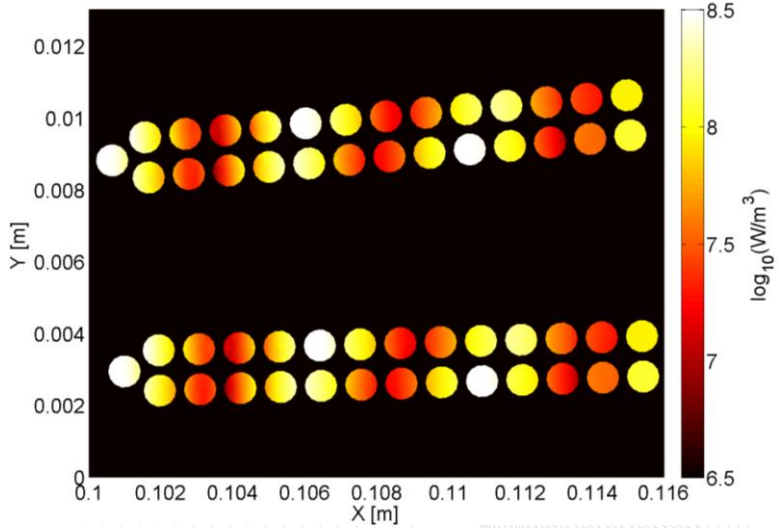


Stator thermal analysis



Motor/Generator efficiency mapping





Eddy current losses in magnets and stranded conductors

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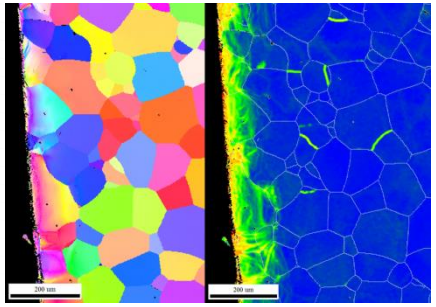
Advanced Modeling Techniques

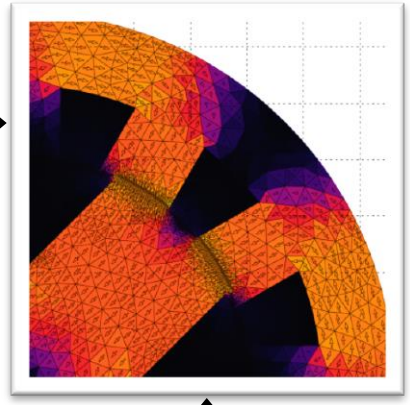
Awarded an allocation of supercomputer 2.25 million core hours
2D FEA code successfully working

Stress Distribution

- Function of cutting/stamping method
- Influenced by mechanical fastening
- Impacted by rotation and other forces

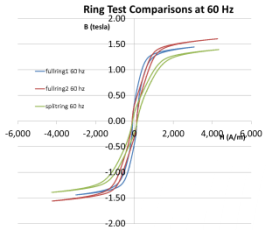


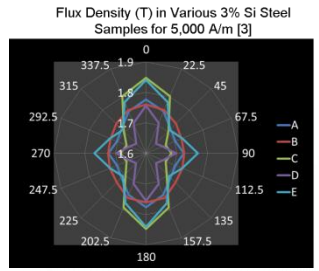
Advanced FEA Modeling Tool



Bulk Characterization

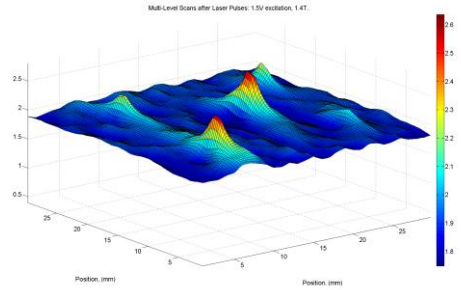
- Traditional Epstein and ring specimen testing at various temperatures
- Custom analysis of rotational losses, anisotropic magnetization/loss, PWM, etc.





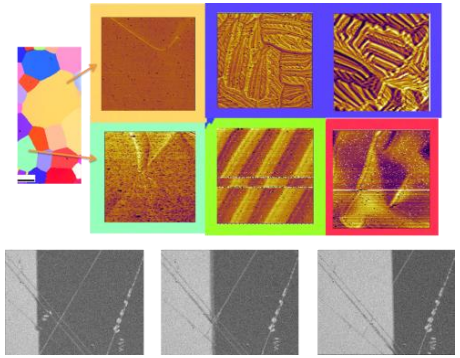
Localized Magnetic Properties

- Function of stress distribution
- Magnetization and loss characteristics are not homogeneous



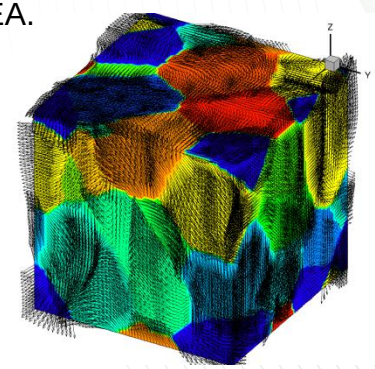
Empirical Magnetic Domain Analysis

- Traditional Epstein and ring specimen testing
- Impacts of stress, pinning, etc. upon domain wall movement, and ultimately magnetization/loss properties.



Theoretical Magnetic Domain Analysis

- Fundamental theory to confirm and supplement empirical findings.
- Indirect link to FEA - too computationally intensive for direct use in FEA.



Slide Credit: *Tim Burress*

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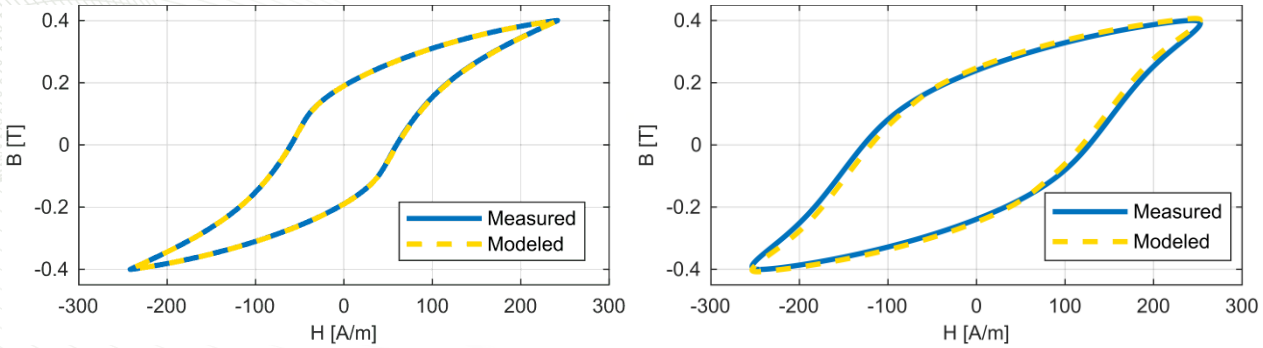
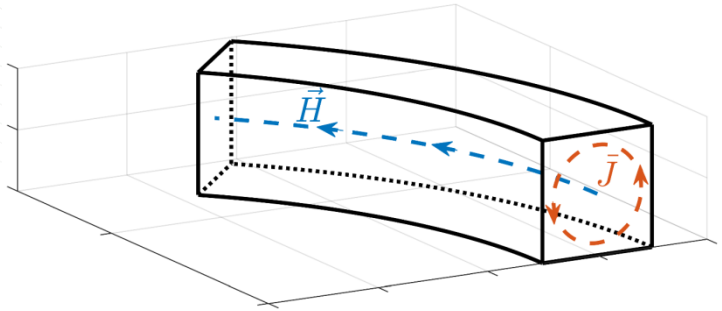
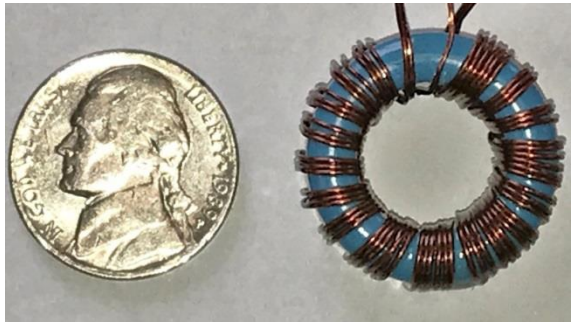
Hysteresis and Eddy Current Loss Modeling



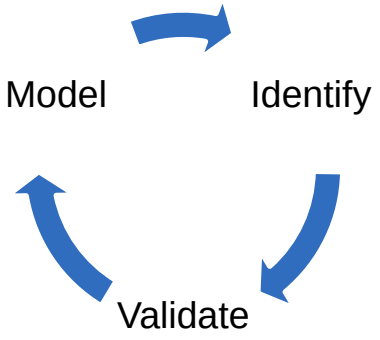
M19 silicon steel B-H loop at 5Hz (left) and 500Hz (right)

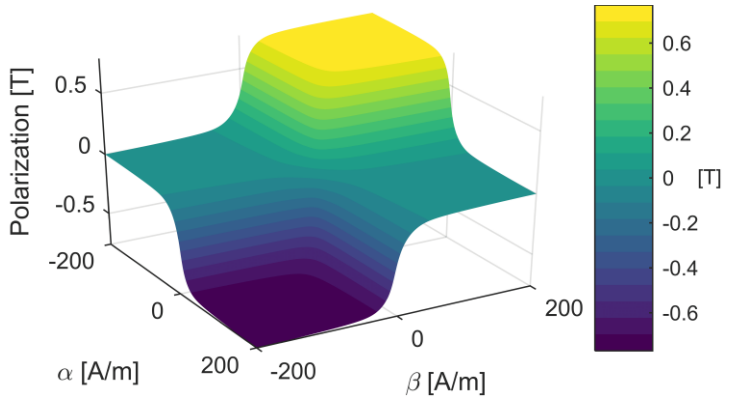


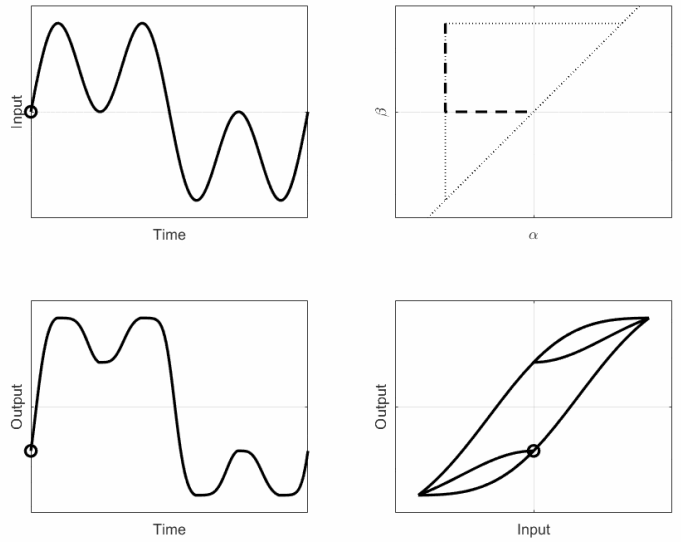
Ring core field in axisymmetric coordinates



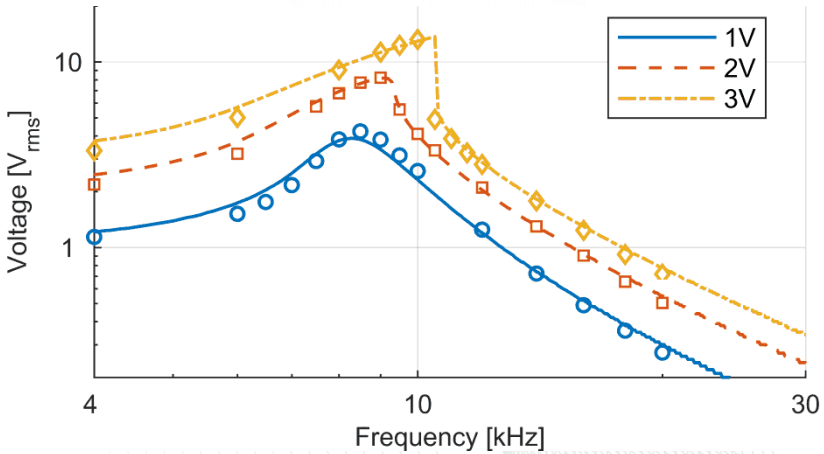
Ferrite toroid and associated Everett function (right)







Preisach hysteresis model animation



Experimental Validation

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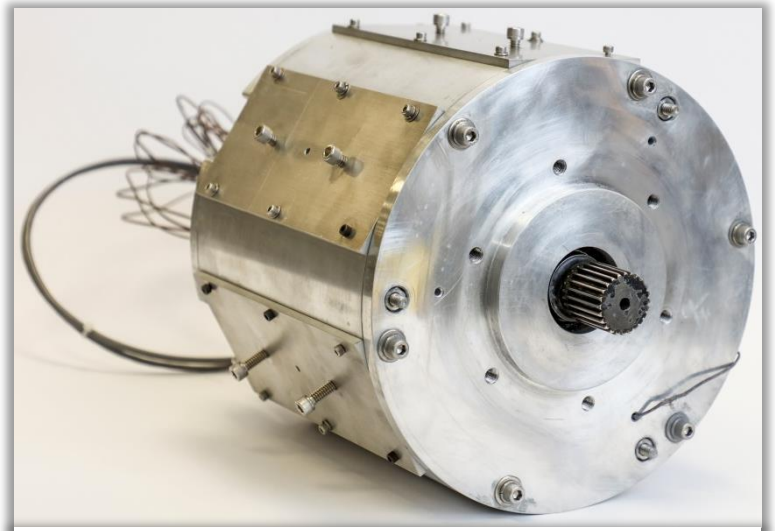
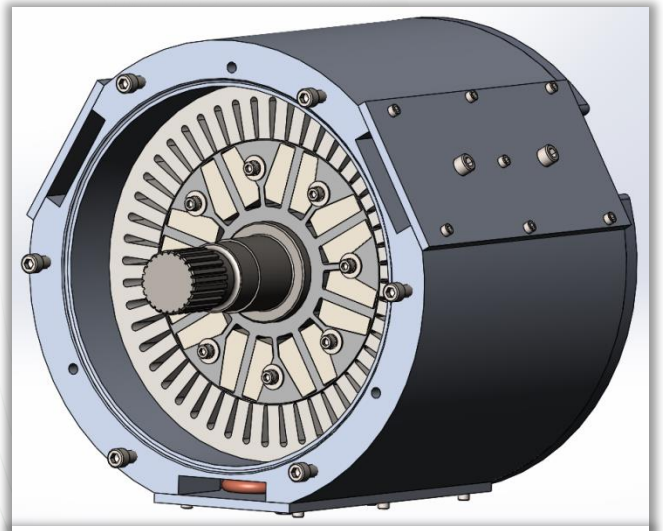
Ferrite Interior Permanent Magnet Machine

- **Key Challenges**
  - Low Energy Product Magnet
  - Rotor Mechanical Strength
- **Results**
  - 103kW peak power
  - Significant increase in power density
- **Awards**
  - DOE VTO Distinguished Achievement Award
  - UT-Battelle Team Research Accomplishment



Ferrite IPM prototype in housing

Ferrite motor dynamometer testing



Ferrite motor model

Team: *Tim Burress, Jason Pries, Randy Wiles, Lixin Tang*

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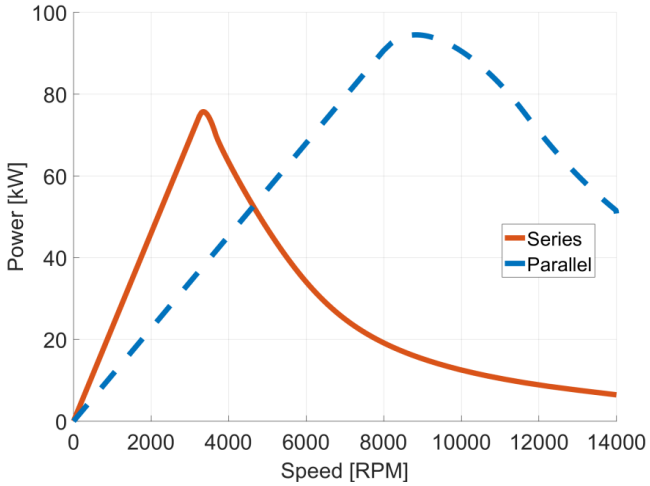
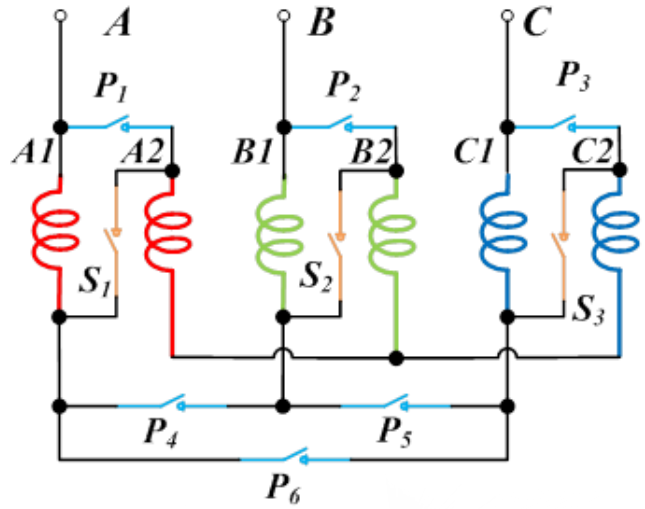
Switched Winding Synchronous Reluctance Machine

- **Key Challenges**
  - Constant power operation
  - Torque density

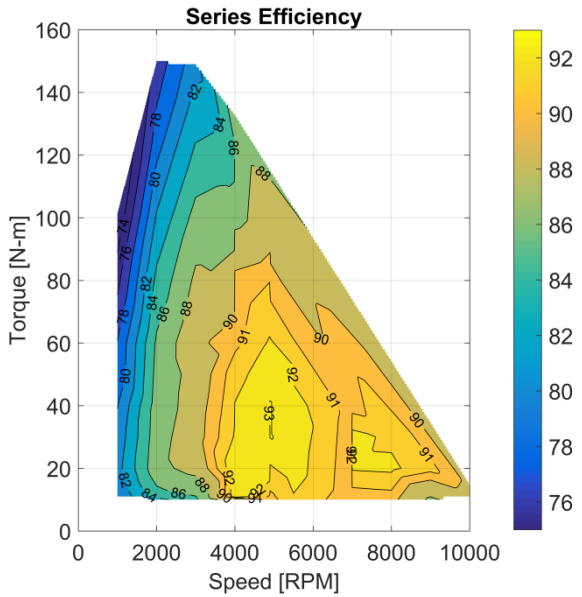
- **Results**
  - 65kW Series
  - 85kW Parallel

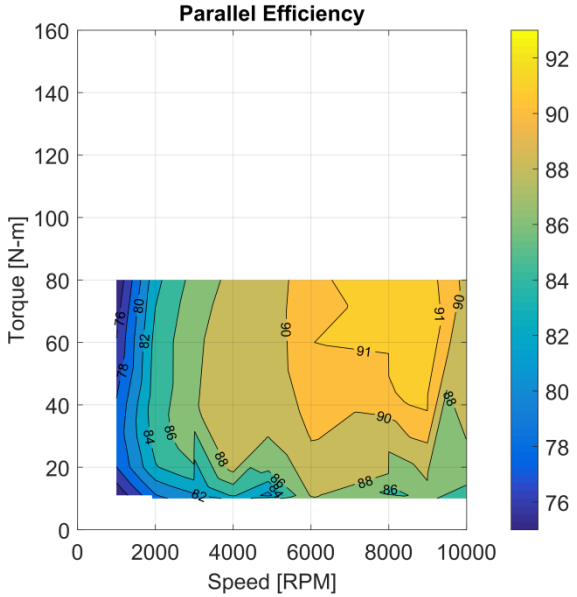


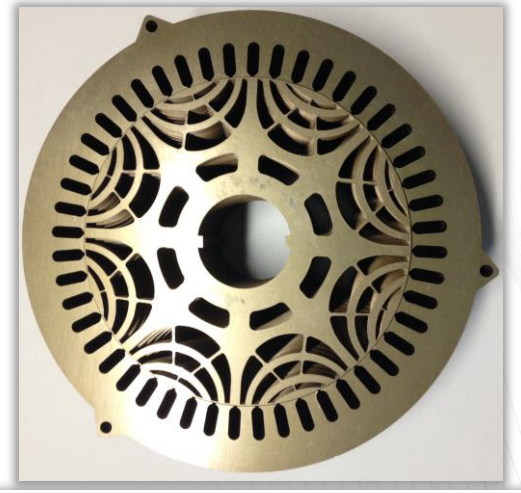
Simulated Two-Mode Power-Speed Characteristics



Winding Switching Configuration







Synchronous Reluctance Machine Lamination Stack

Team: *Tim Burress, Jason Pries, Randy Wiles, Lixin Tang*

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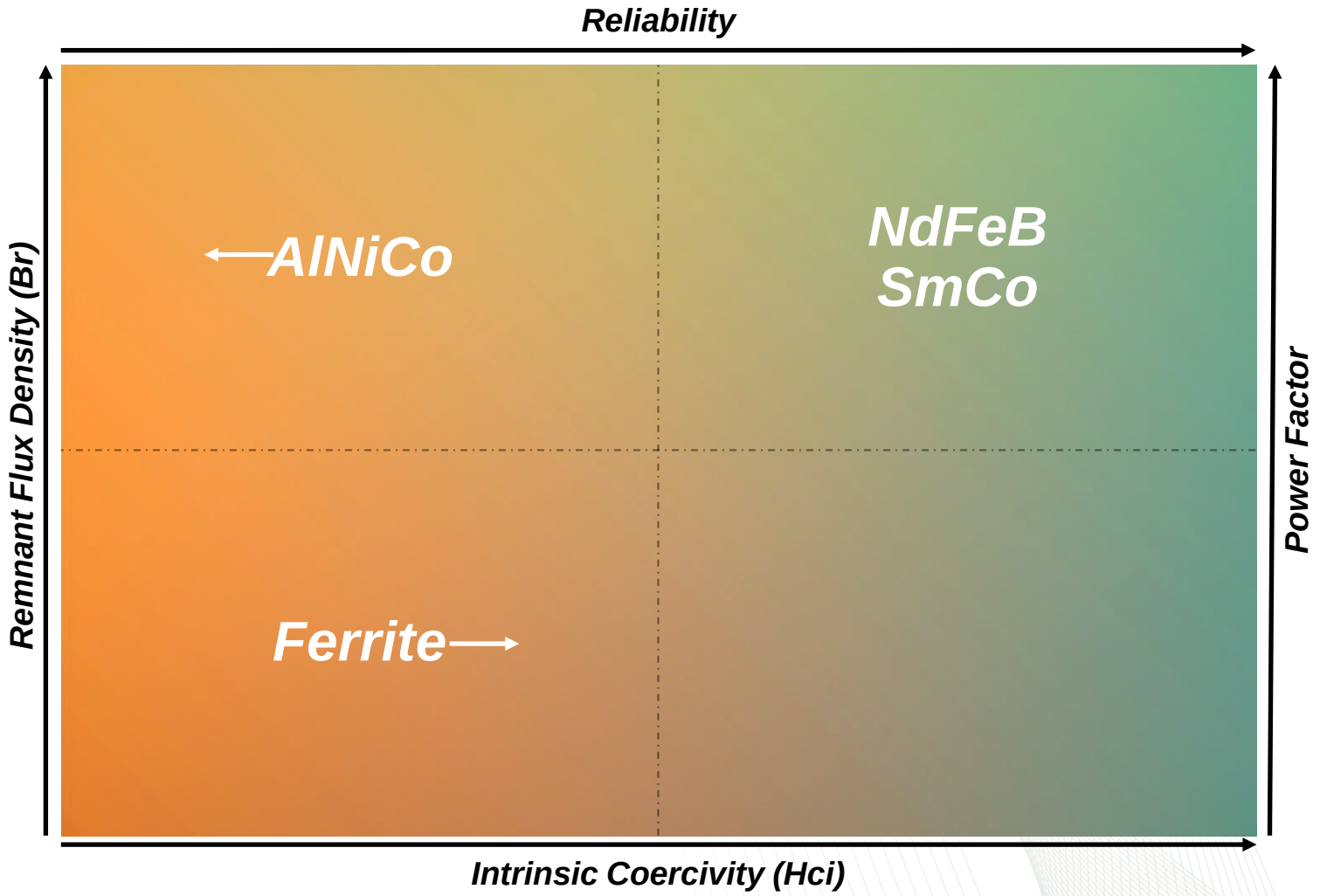
Non-Rare Earth Electric Motors

- **Challenges**
  - Power Factor
  - Reliability
- **Energy product?**
  - Coercivity is important for automotive applications
  - Ways to work around low remnant flux density
  - Would trade Br and BHmax for Hci



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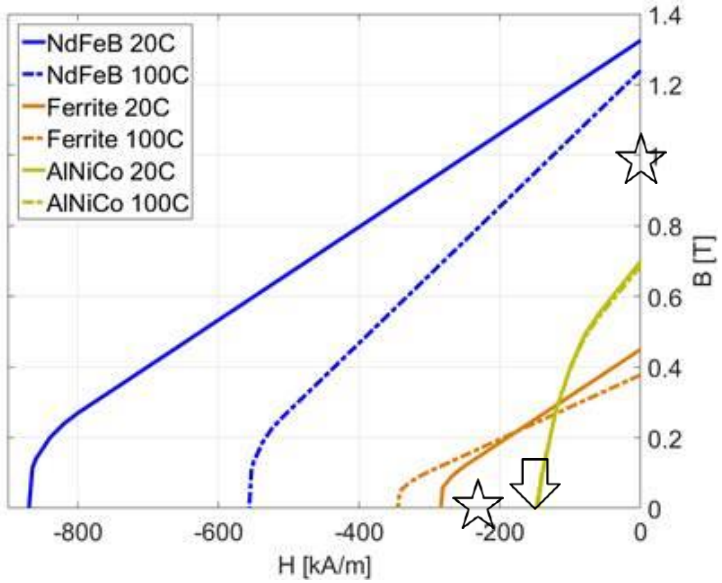
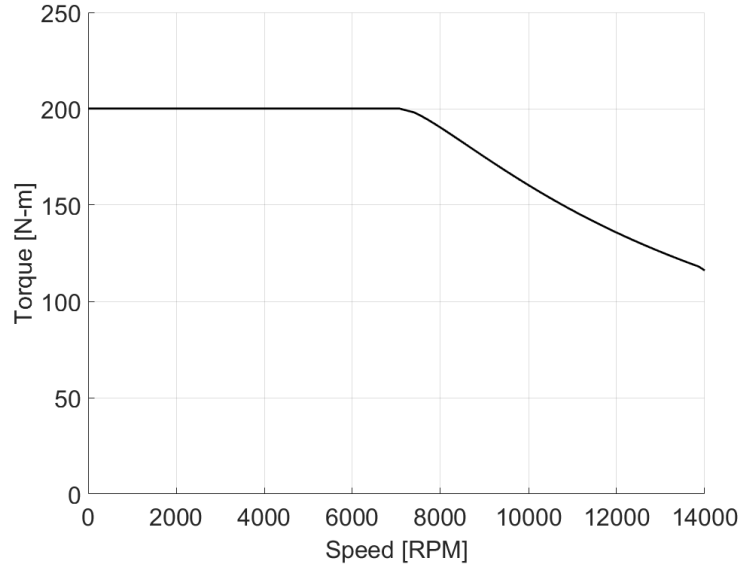
High Energy Product AlNiCo

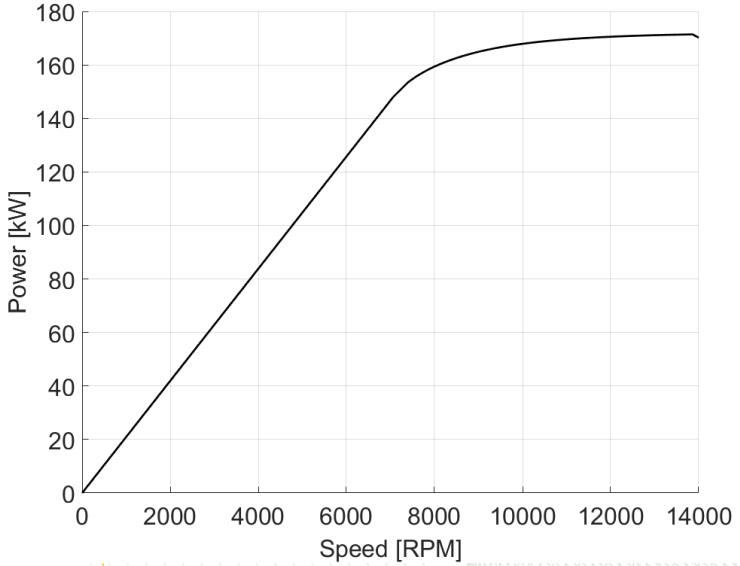
- Redesign of ferrite motor using hypothetical AlNiCo material (simulation)



Peak Torque	200N-m
Peak Power	148kW
Torque Density[3]	25.6N-m/L
Power Density[3]	19.0kW/L
Specific Torque[3]	7.32N-m/kg
Specific Power[3]	4.95kW/kg
Characteristic Current	200Arms
Peak Demagnetizing Field[4]	2300Oe

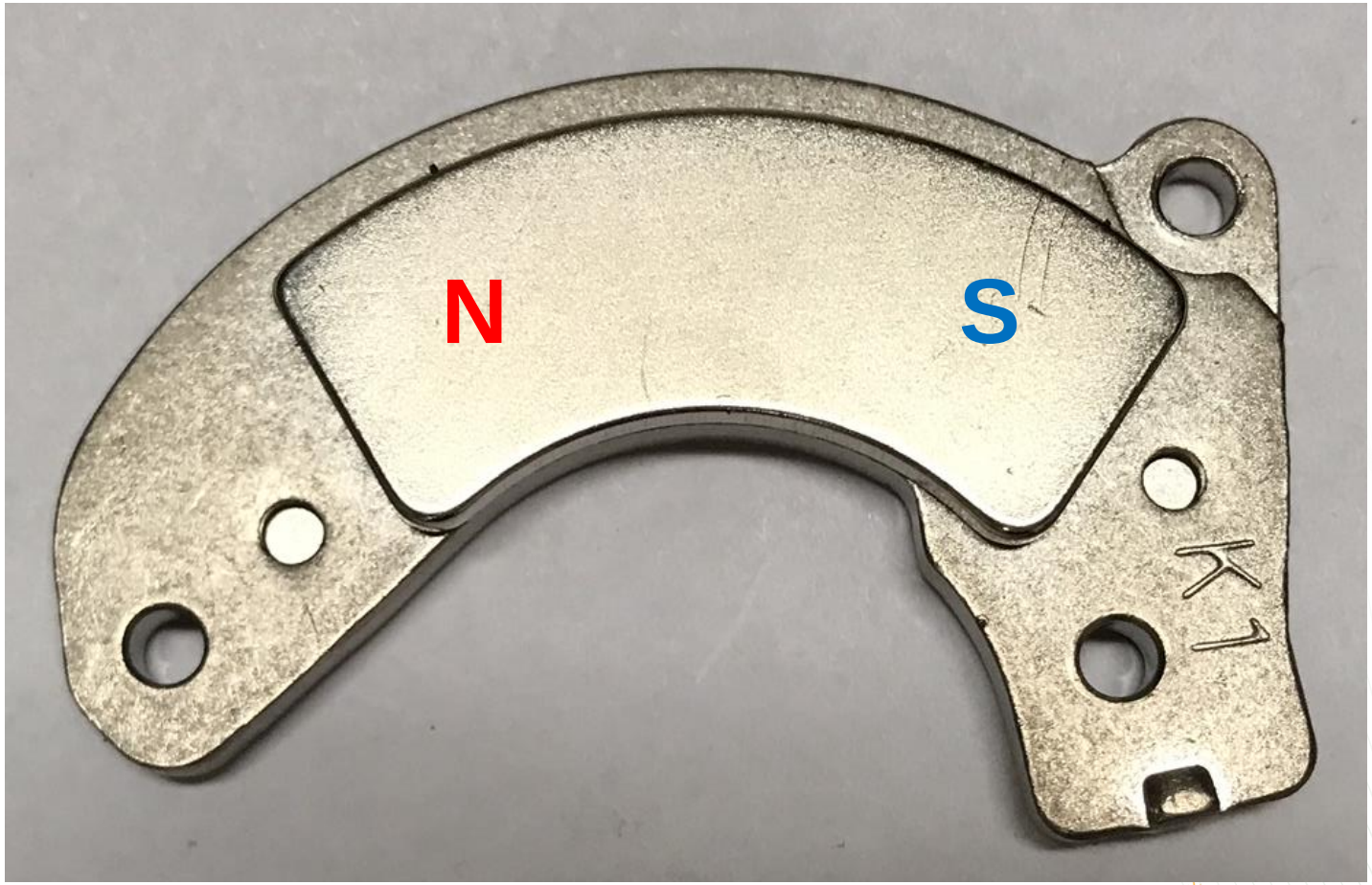
[3]Based on Active Length + End Turn + Cooling Jacket volume
[4]During short circuit operation, averaged over cross section





Recycled Hard Drive Magnet Motors

- **Can we repurpose magnets designed for other applications?**
  - NdFeB
  - Unique shape and magnetization pattern for motor applications



Contact: *Tim McIntyre*

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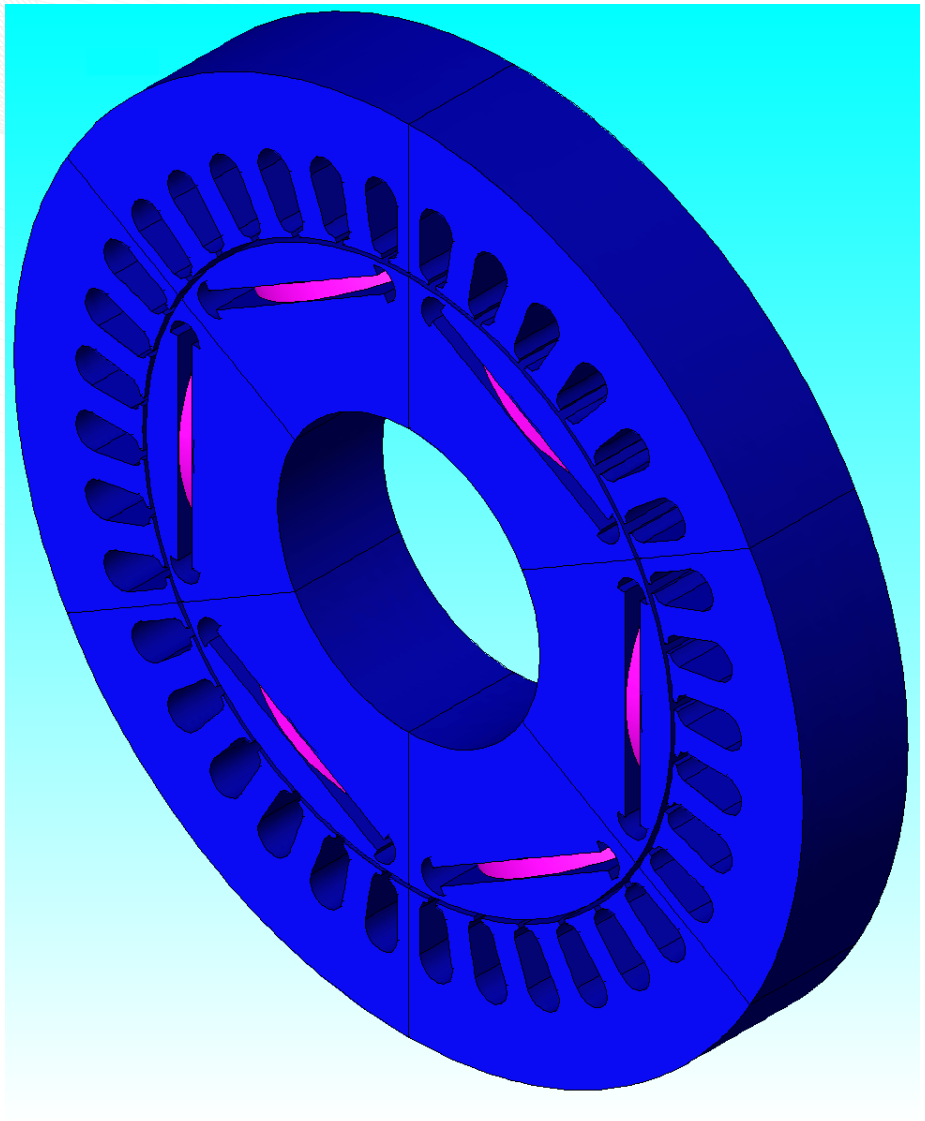
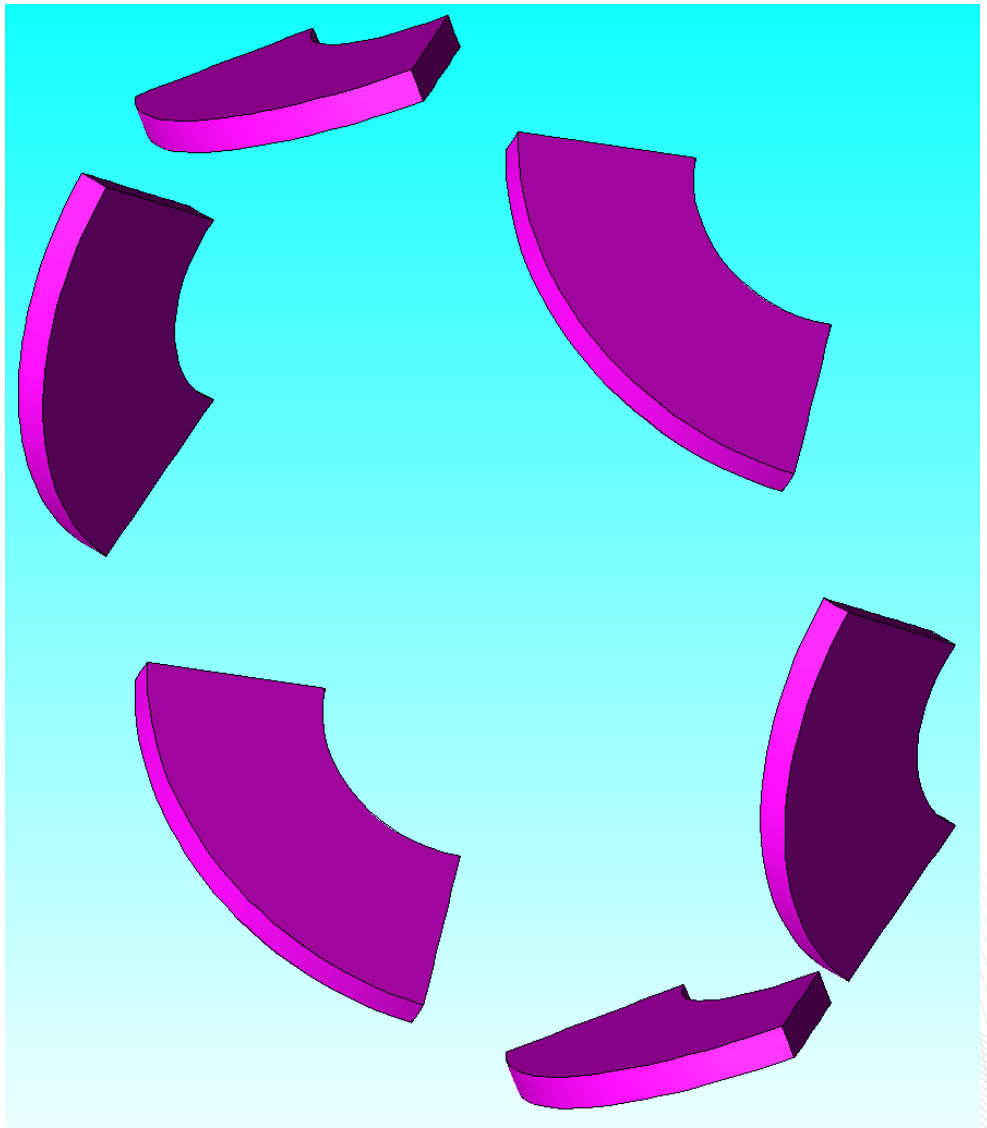
Recycled Hard Disk Drive Magnet Motors: Radial Flux





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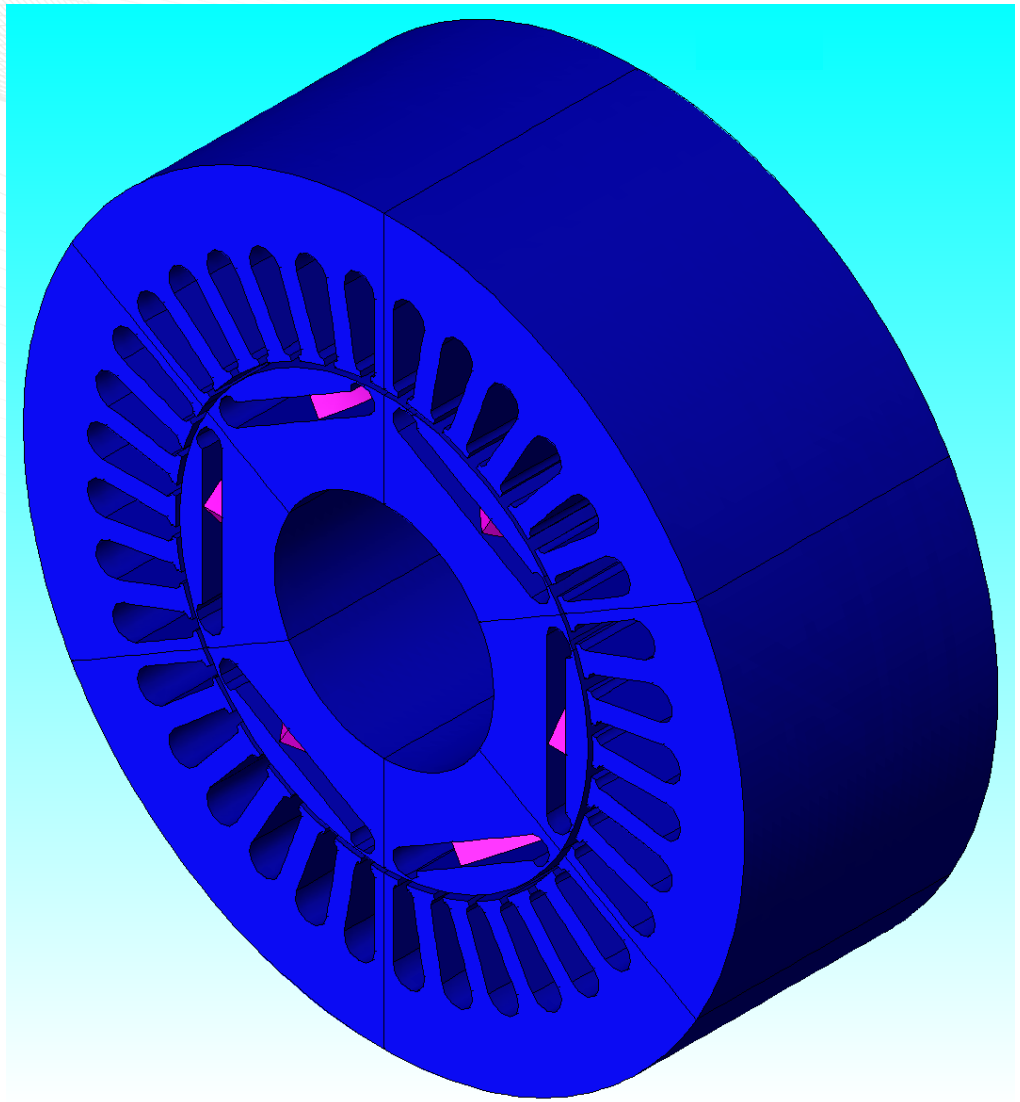
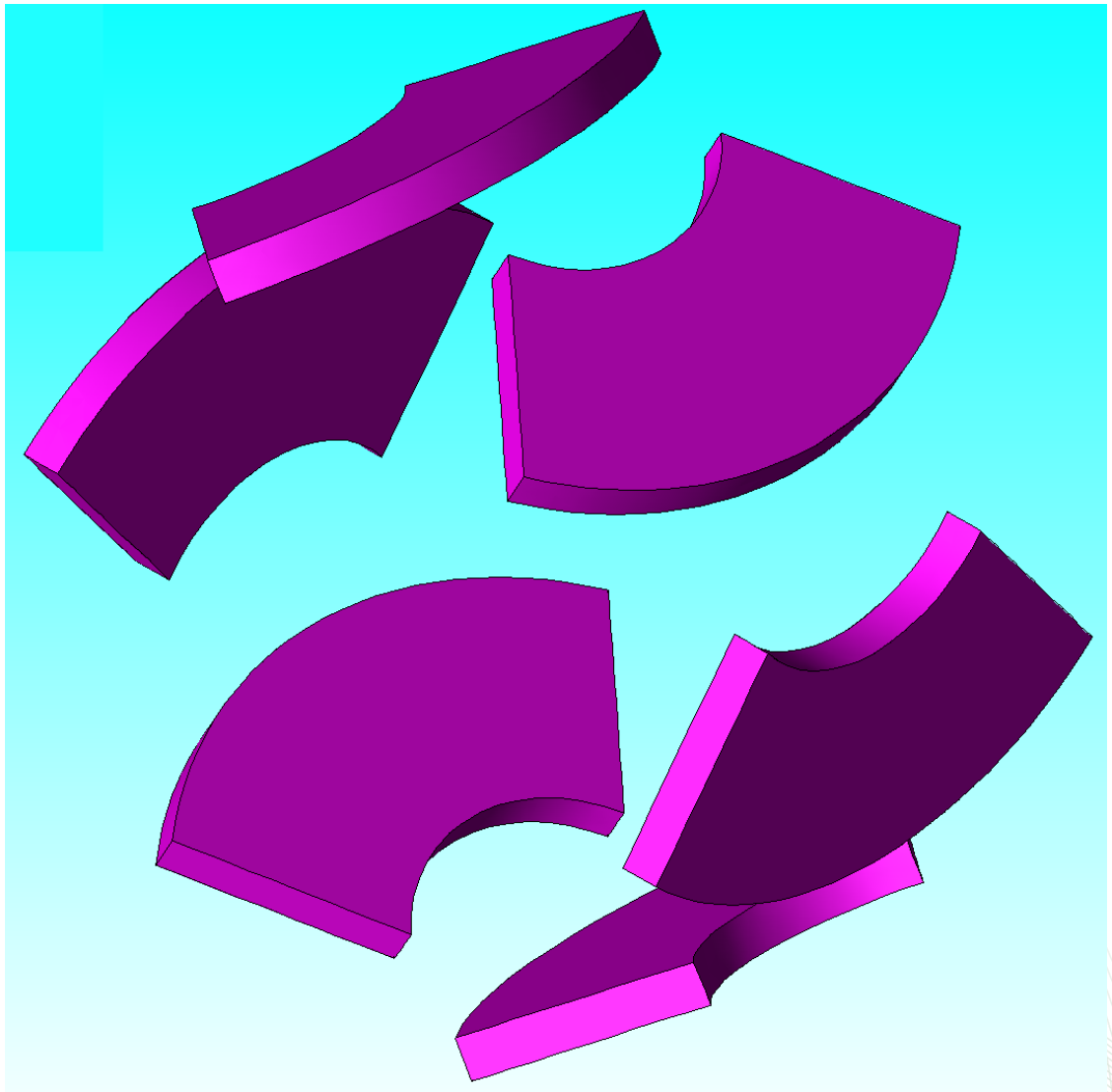
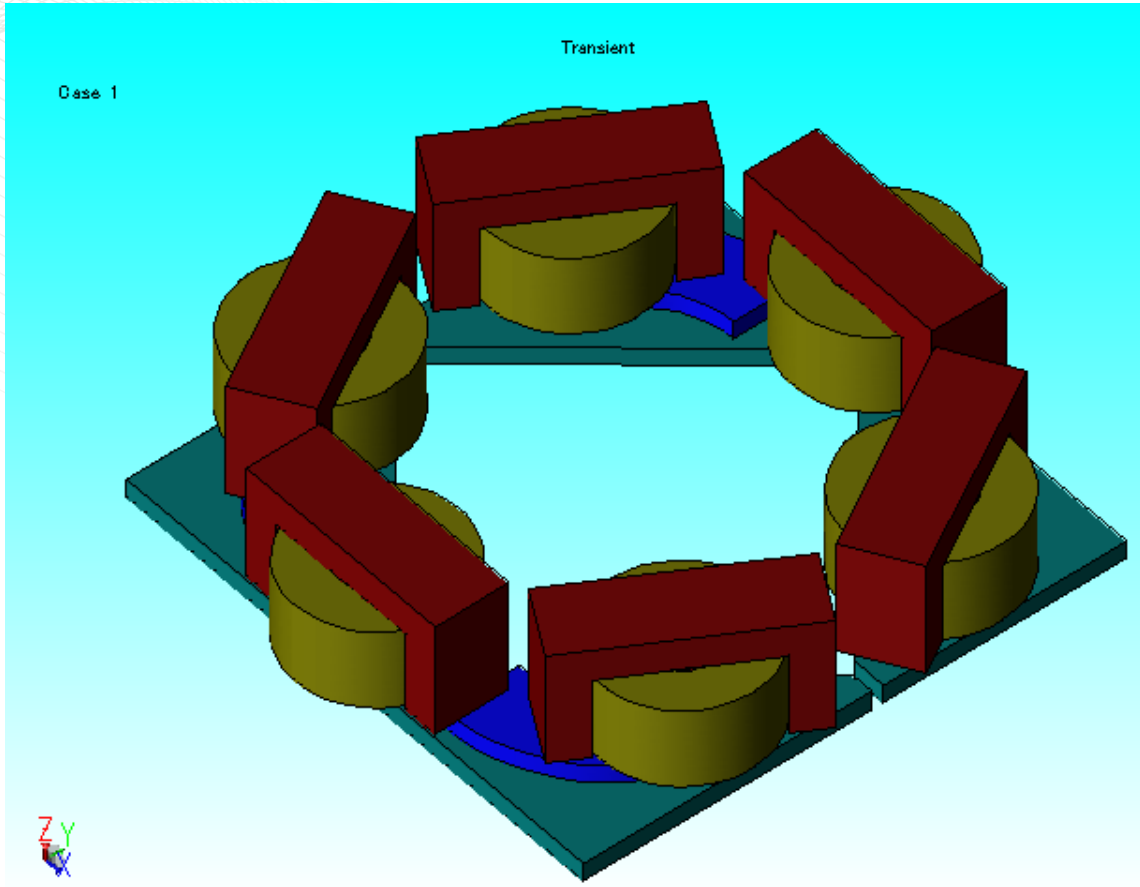
Recycled Hard Disk Drive Magnet Motors: Radial Flux

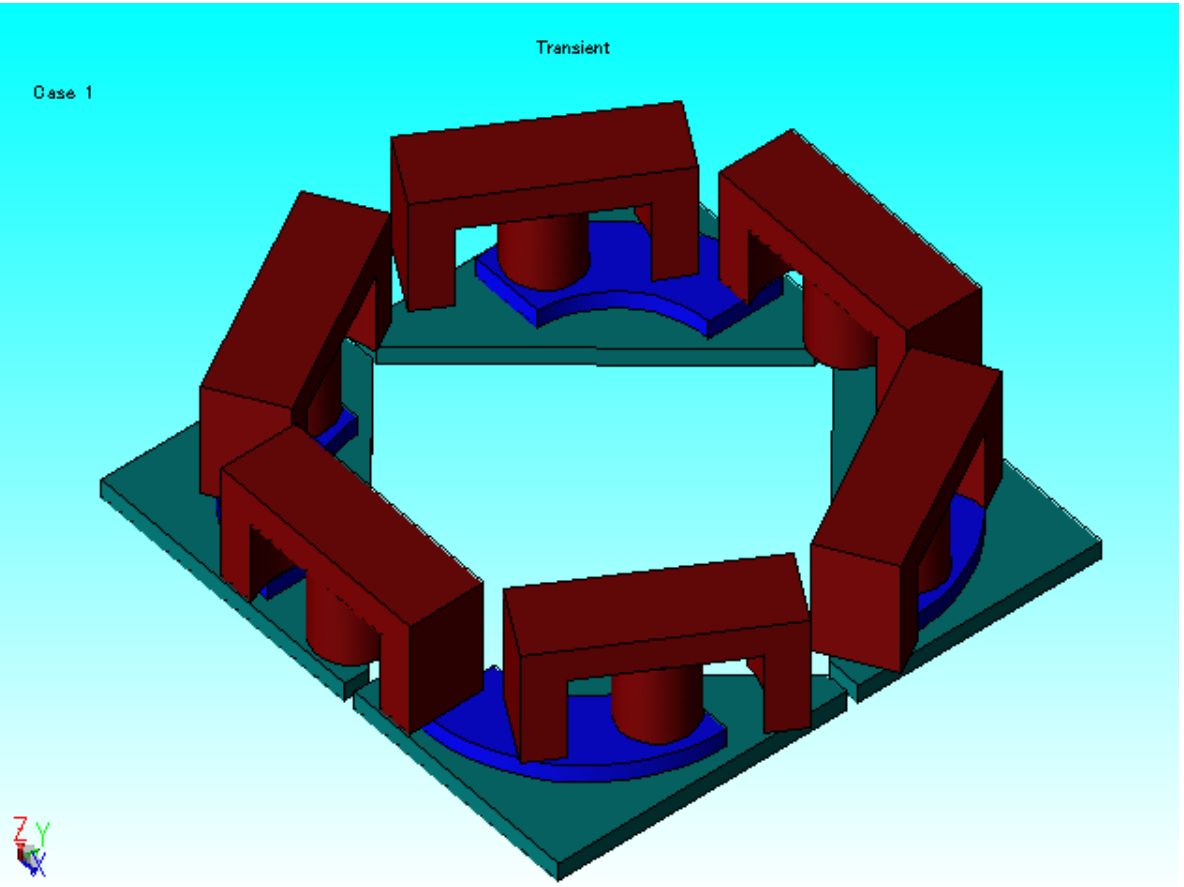




Contact: *Tim McIntyre*

Recycled Hard Disk Drive Magnet Motors: Axial Flux v1





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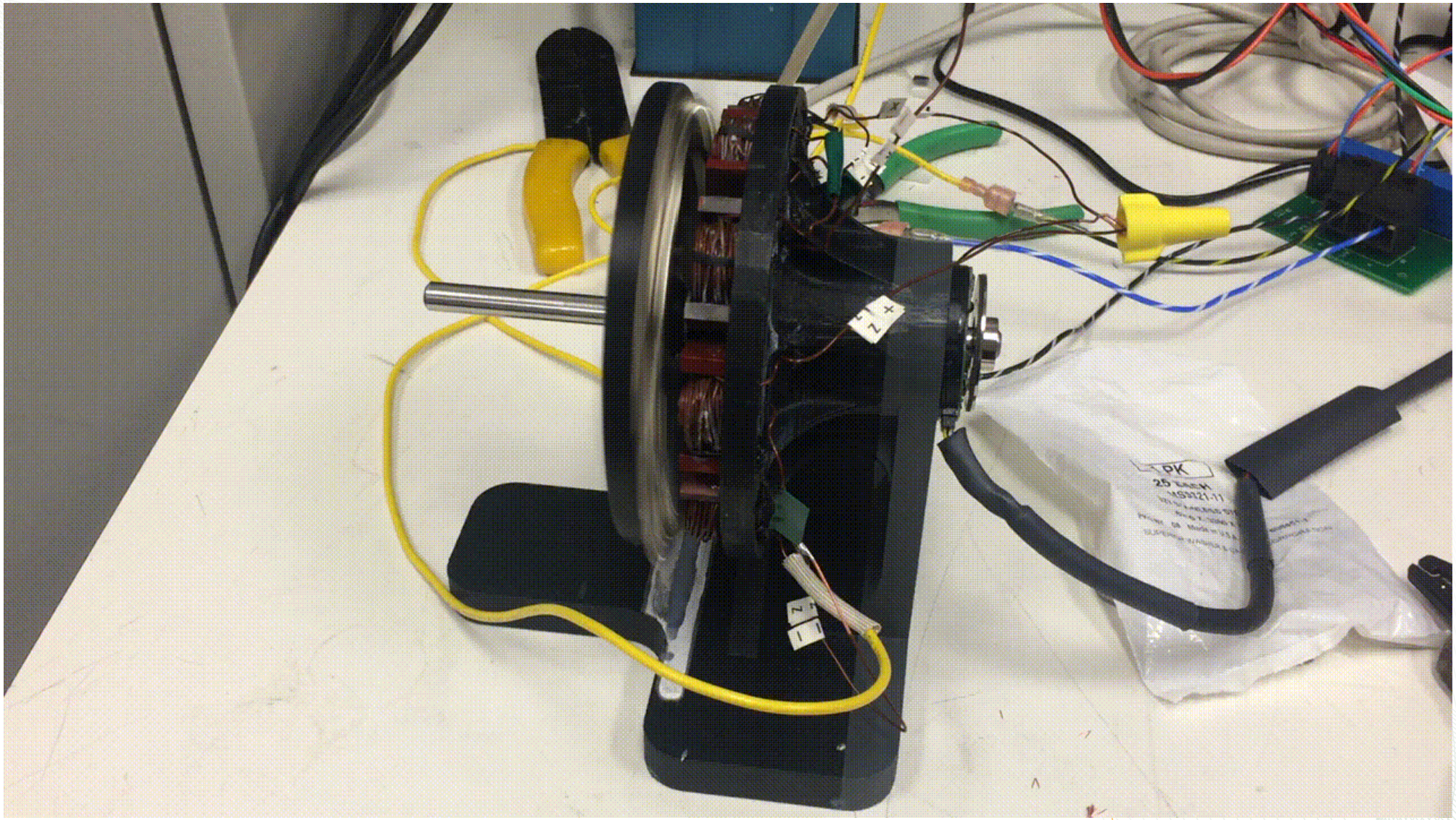
Recycled Hard Disk Drive Magnet Motors: Axial Flux v1



Contact: *Tim McIntyre*

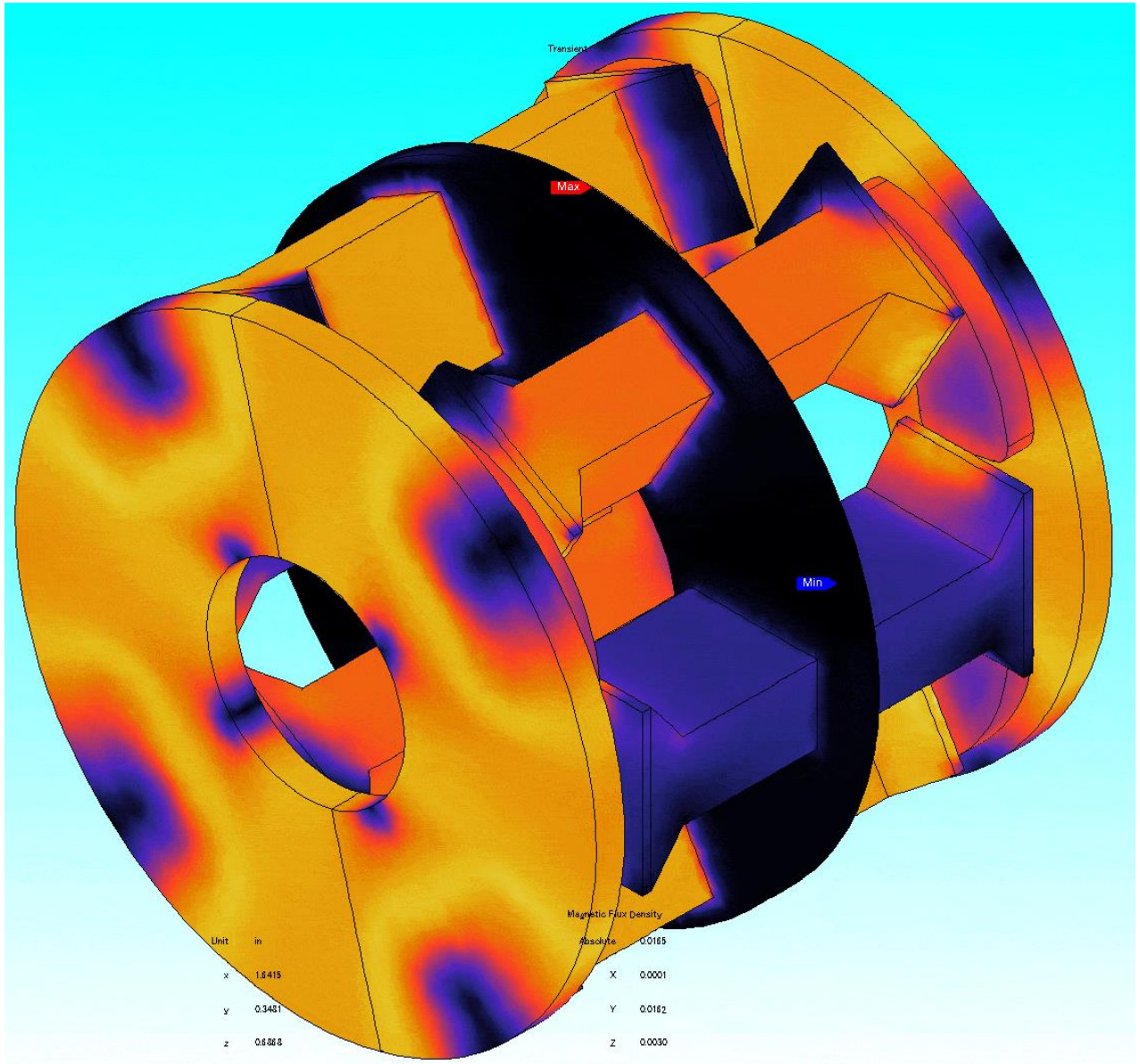
Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

Contact: *Tim McIntyre*

Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

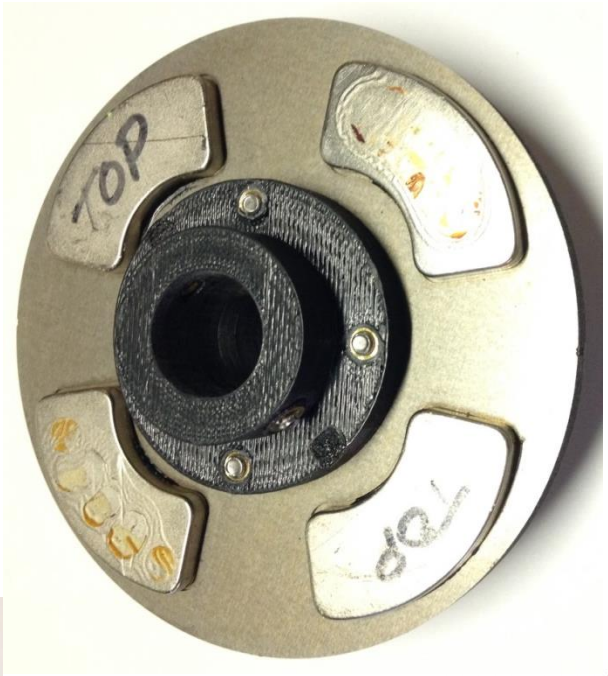
- **Dual Rotor Axial Gap Motor**
  - Balanced axial forces
  - Reduced torque ripple by rotor angular displacement
  - Difficult construction

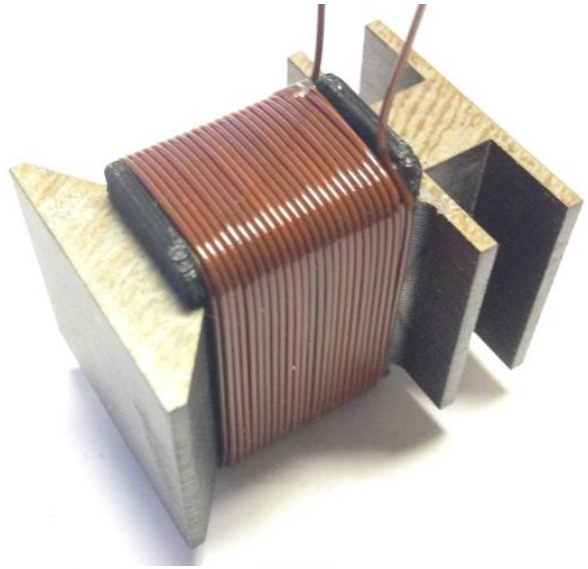
- **Dual Stator Axial Gap Motor**
  - Balanced axial force
  - Reduced torque ripple by stator angular displacement
  - Easier construction

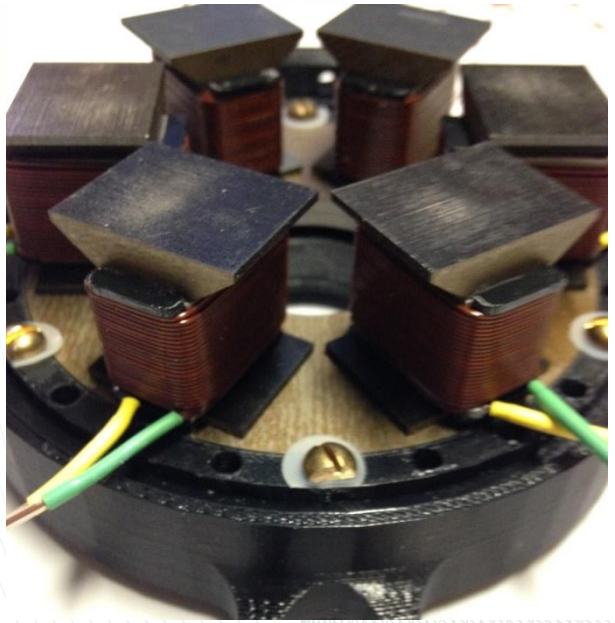


Contact: *Tim McIntyre*

Recycled Hard Disk Drive Magnet Motors: Axial Flux v2







Contact: *Tim McIntyre*, ***Photo Credit:*** *Randy Wiles*

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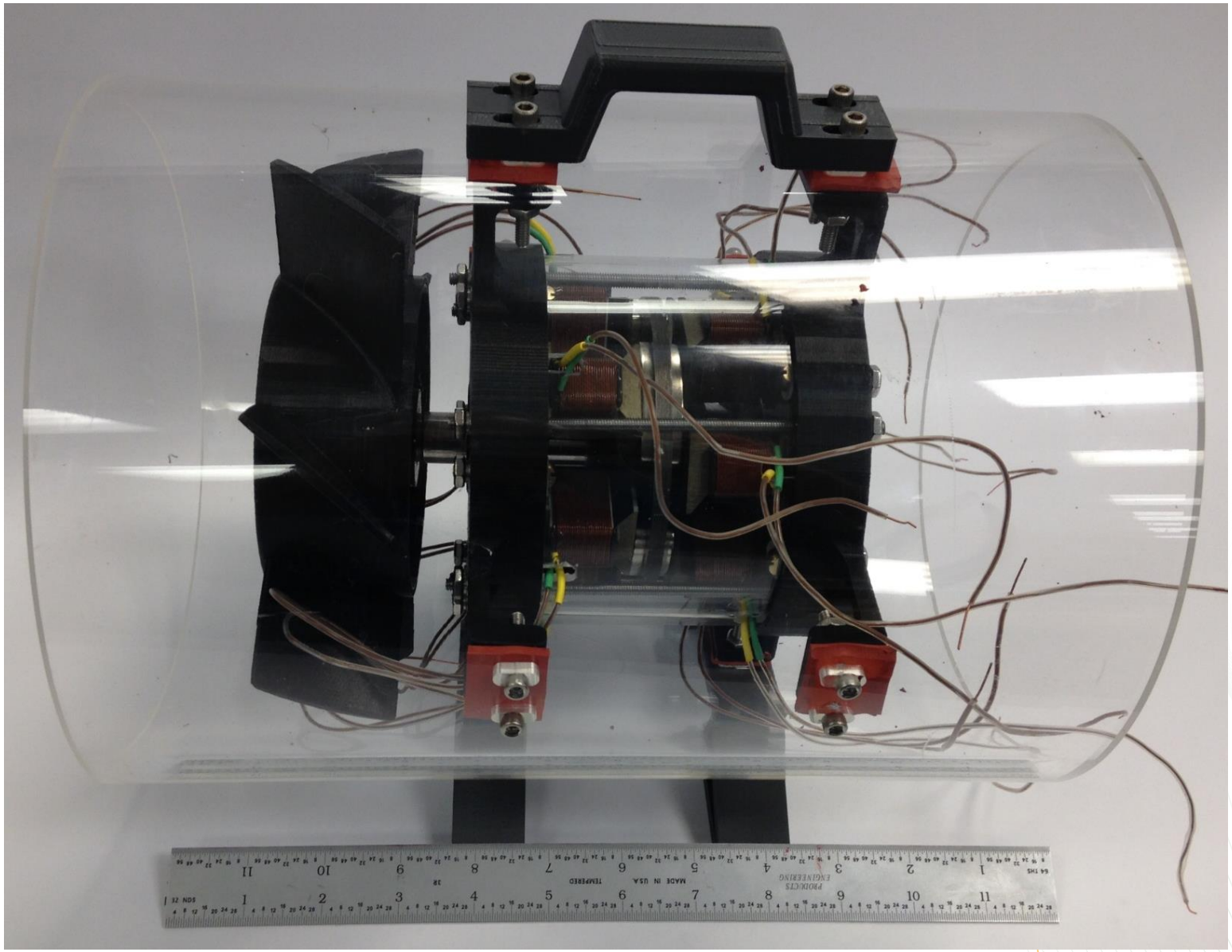
Recycled Hard Disk Drive Magnet Motors: Axial Flux v2



Contact: *Tim McIntyre*, ***Photo Credit:*** *Randy Wiles*

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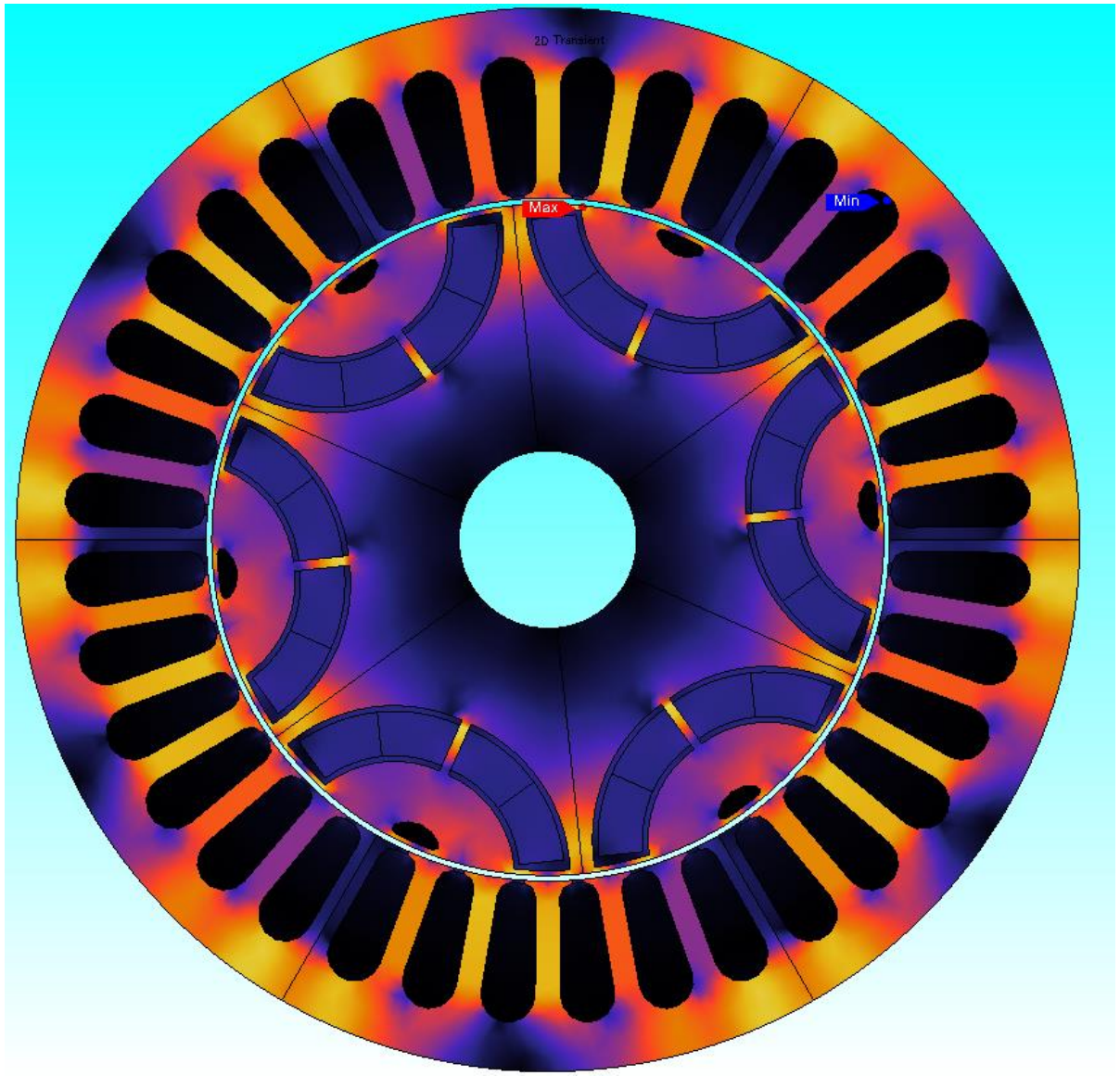
Printed Magnet Motors

- **Motor manufactures prefer simple magnet shapes due cost**
  - Tooling
  - Grinding/Finishing
- **Potential untapped optimization benefits using unconstrained magnet geometry**



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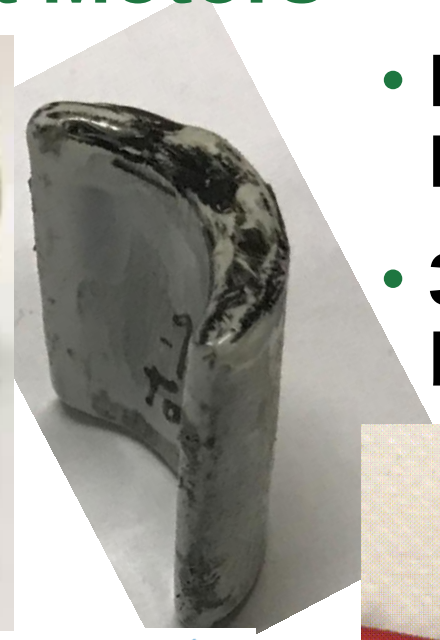
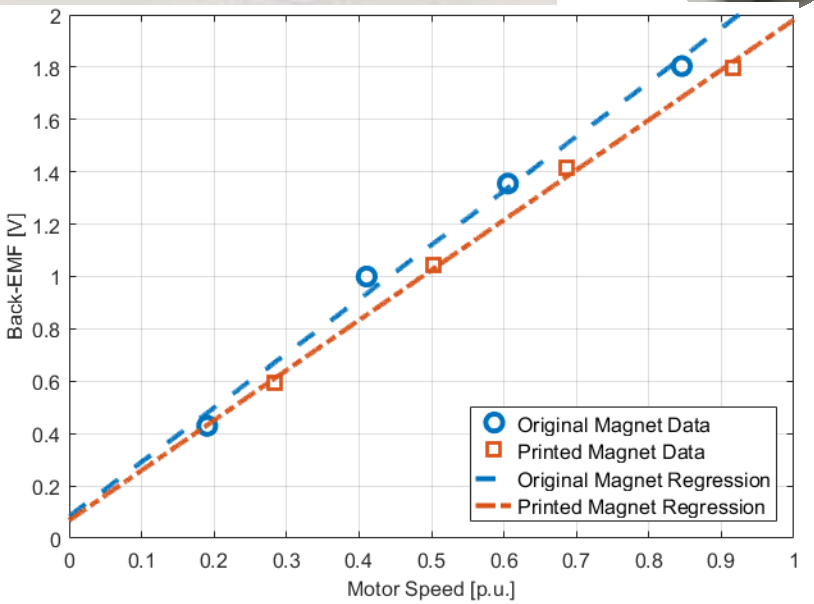
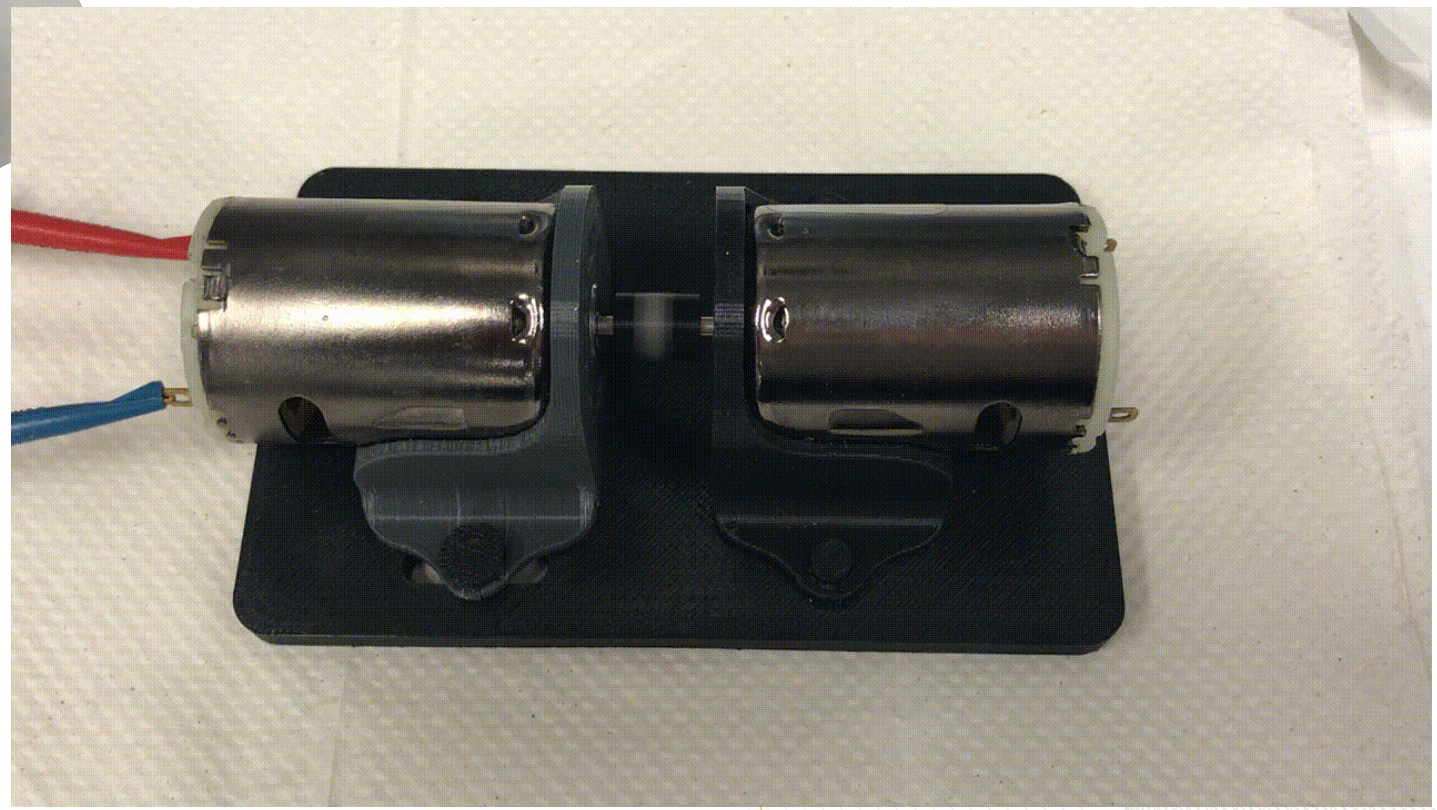
Printed Magnet Motors





- **Replace sintered ferrite with printed NdFeB**
- **3D printed small mounting plates for back-to-back testing**



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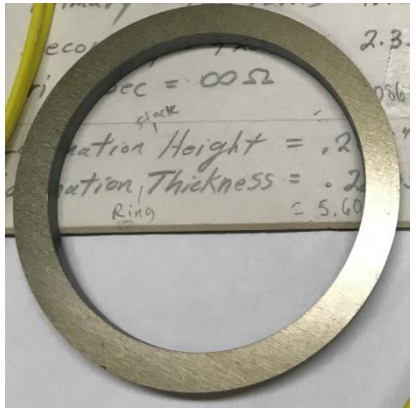
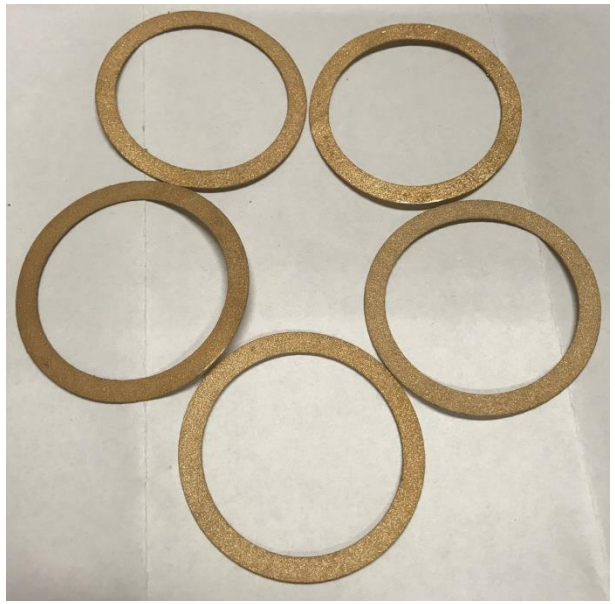
New Materials

- **Printed Laminations**
  - Stators
  - Inductors
  - Induction Machine Rotors



- **Magnetic Characterization**
  - Ring Test
  - B-H Curve
  - Core Losses



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Next Generation Motors

- **Displace Existing Materials?**
  - Materials, manufacturing drive topological decisions
  - Well optimized designs push materials to their limits

- **Displace Existing *Designs***
  - New materials
  - New designs

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Questions and Discussion?

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